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Traffic Barrier Performance

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RESEARCH REPORT 155

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TRAFFIC BARRIER PERFORMANCE

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16. Abstract

This report summarizes research on traffic barrier performance conducted by New York from 1983 through 1987, which concentrated on 1) development of height standards and tolerances for light-post barriers, 2) barrier performance related to vehicle characteristics, 3) development of an economic model to compare median barrier costs, and 4) effects of curbs on barrier performance. Department of Motor Vehicles computerized and hard-copy accident reports, Department of Transportation records, and on-site inspections provided highway and barrier information. Accident data were obtained for approximately 3300 accidents occurring between July 1, 1982 and June 30, 1983. Of these, about 1700 were at light-post barrier sites. In addition, frontal-geometry was measured on vehicles in parking lots and automobile showrooms. Based on analyses of the available information, no optimum mounting height was found for any of the barrier systems that might result in reduced injuries, increased redirection, or reduced risk of a secondary event (i.e., roll-over, hitting a fixed object, etc.). The trend toward lower frontal-geometry suggested that a barrier height lower than those specified at the time accident data were collected, would reduce the risk of underride. The lower frontal-geometry in itself reduced the danger of override. An economic model was developed to compare median barrier costs. Based on the findings, it was recommended that a standard center-of-rail height of 24 in. be used for all light-post barriers. This resulted in top-of-rail height of 27 in. for cable and box-beam barrier systems and 30 in. for W-beam barriers.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

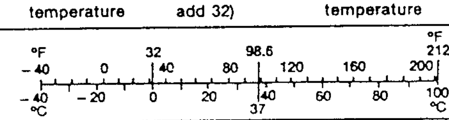
Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

CONTENTS

I. INTRODUCTION

New York State's light-post traffic barriers were developed and perfected during the 1960s. Field performance evaluations conducted then and in the early 1970s confirmed that these barriers provided excellent protection to errant vehicles. However, by 1983, when this study was initiated, substantial changes in vehicle design had occurred and smaller, lighter vehicles composed a larger portion of traffic on the road. In addition, many highways where these barriers were installed had been overlaid, and some were soon to be overlaid a second time, resulting in changes of several inches in effective barrier height. Also, other barrier types were in service, composed of both early designs that might be reaching the end of their useful life and new designs used in special situations.

Thus, information was needed to relate severity of barrier accidents to vehicle size and type, barrier type and mounting height, and roadway features. With this information, Department designers could select the best barrier type to accommodate traffic, as well as establish reasonable standards and tolerances for barrier mounting heights.

A. Objective

The objective of this research was to determine how impact severity on New York State traffic barriers was affected by vehicle size and weight, barrier type and mounting height, and roadway features.

B. Background

In the 1960s, the Department developed a system of traffic barriers using a new concept of light, yielding posts. The standard post was an S3x5.7 rolled-steel section. Rail elements consisted of steel cable and corrugated steel beam (W-beam) acting as tension members, and 6- by 6- by 3/16-in. and 6- by 8- by 1/4-in. welded steel tubes (box-beams) acting as bending members. The original standard designs placed the center of each rail type 24 in. above ground. However, subsequent accident investigations indicated that for vehicle configurations common around 1970, improved vehicle containment could be achieved by increasing center-of-rail heights to 27 in. (1). That change was implemented from 1969 through 1971. No allowable tolerance was provided on the standard sheets, but rail mounting heights were listed as "nominal." Subsequent field studies, however, revealed that deviations of 1 or 2 in. from the standard height were common (2).

The 1977 AASHTO traffic barrier guide (3) contained information on desirable mounting heights and tolerances for all barriers then in common use, including New York's light-post systems. Some recommended heights matched New York standards in force when this study began, but others matched the original standards that had been 3 in. lower. The guide also recommended a ±3-in. tolerance on guiderail height, and an absolute minimum of 27 in. for median barrier.

Complicating mounting height determination was downsizing of passenger vehicles. The barrier system was originally tested using mostly intermediate and full-size sedans weighing 3000 to 4000 lb. During the 1970s, the oil shortage started a trend toward downsizing and other changes in vehicle configuration. Although vehicle center-of-gravity heights had lowered only slightly (20 to 22 in. was still typical), weight, size, and sheet-metal configurations had changed significantly. Cars were lighter, smaller, and had lower front-end profiles and bumper heights. At the same time, light trucks and vans increasingly constituted a sizable portion of the total traffic, but were much heavier and longer than typical passenger cars. The result was a much wider range of vehicle characteristics to be accommodated by barrier systems.

During this study, a number of presentations were made to professional organizations, and several reports were published. This final report is intended to fulfill requirements of the Federal Highway Administration's Highway Planning and Research Program by briefly summarizing results of this study. Chapter II presents abstracts and conclusions of the published manuscripts, substantially verbatim. Chapter III contains previously unpublished information and final recommendations.

II. TRAFFIC BARRIER PERFORMANCE

A. Development of Proposed Height Standards and Tolerances for Light-Post Traffic Barriers (Research Report 111, April 1984)

When New York's light-post traffic barrier systems were adopted in the mid-1960s, top-of-rail heights were specified at 27 in., except for W-beam median barrier set at 29 in. Those heights were based on then-current standards for other barrier systems, analysis of vehicle and barrier geometry, and full-scale crash tests. In 1969, top-of-rail heights were increased to 30 in. for cable and box-beam and 33 in. for W-beam. That change occurred after vehicles vaulted in a small number of barrier accidents, mostly involving W-beam. However, the change was also supported by an analysis of geometric characteristics of vehicles common at that time, which indicated that certain bumper and sheet-metal configurations contributed to the vaulting problem.

The heights implemented in 1969 are still in effect on current (1984) standard sheets. However, in the late 1970s, barrier heights again became a concern when a large number of R&P projects were found to have barrier heights substantially below current standards. Some had been installed at the original (lower) standard, while others were low from normal construction and maintenance variation, post settlement, or subsequent pavement overlays. Addition of overlays in the planned projects sometimes resulted in effective barrier heights much lower than current standards. Correction of all low barriers would be very expensive and difficult to justify in terms of increased safety, especially where few accidents were expected. On the other hand, very low barriers could not be expected to perform well, and a significant safety benefit might result by correcting rail heights on some projects. Until then, barrier height corrections had been handled on a project-by-project basis. Further complicating the problem, an obvious shift in vehicle geometry had occurred over the previous decade. It became apparent that hood heights on many newer cars were very low relative to traffic barriers mounted to then-current standards. Several recent barrier accidents involving rail underride had been noted by New York research engineers, adding to this concern about impacts by low vehicles.

In January 1983, the Engineering Research and Development Bureau began planning a large-scale accident investigation to relate traffic barrier performance to rail height (4). However, because of the massive effort required to collect and analyze the large volume of accident data, development of new rail heights and tolerances would not be completed for some time. The Engineering Research and Development Bureau was thus given the assignment of developing proposed interim heights and tolerances that could be used on R&P projects, until new standards were developed based on results of the planned research. This report describes development of the interim standards, based on four sources of information:

1. New York State and AASHTO height standards and tolerances,

2. Full-scale barrier tests,

3. New York State barrier accident experience, and

4. Vehicle geometric characteristics.

1. Abstract

Current New York State height standards for light-post traffic barrier are based on crash tests, in-service accident experience, and analysis of vehicle geometric characteristics. However, those standards were set in 1969. Analysis of the geometric characteristics of current vehicles reveals that if mounting heights were lowered 3 in., the railings would provide improved protection against vehicle underride and still provide good protection against vaulting. Crash-test data and extensive accident experience indicate that barriers mounted at this lower height will continue to perform well, even when a ±3 in. tolerance is permitted. Current New York State and AASHTO standards and the proposed new standards are as follows (it may be possible to increase the range of allowable heights after completion of research now planned or underway):

Current and Proposed Height Standards, in. (top of rail)

Barrier Type	1982 NYS Standard	1977 AASHTO Standard	1977 AASHTO Minimum	Proposed NYS Standard	Proposed NYS Minimum
Guiderail					
Cable	30	30	27	27	24
W-beam	33	30	27	30	27
Box-Beam	30	27	24	27	24
Median Barrier					
W-Beam	33	33	27	30	27
Box-Beam	30	30	27	27	24

2. Discussion and Summary

Analysis of current vehicle geometries suggests that rail heights of 27 in. for cable and box-beam barriers and 30 in. for W-beam provide good protection against both underride and vaulting. These heights provide margins of at least 6 in. to accommodate suspension travel, sheet metal contact, and other variables for all except a few low-volume specialty cars, and some 4x4 utility vehicles and heavy-duty pickups. Adopting the suggested AASHTO height tolerance of ±3 in. still provides a margin of several inches for most vehicles. Review of available crash test and in-service accident data indicates that both the suggested heights and tolerances can be expected to provide satisfactory performance. In fact, many barriers now in service on state highways are within the proposed height range, and accident records indicate good performance.

Based on results of this analysis, the following mounting heights (top of rail) for light-post barriers are recommended:

Barrier Type	New Construction or Adjusted for Height	Tolerance Max.	Tolerance Min.
Cable Guiderail	27 in.	30 in.	24 in.
Box-Beam Guiderail & Median Barrier	27 in.	30 in.	24 in.
W-Beam Guiderail & Median Barrier	30 in.	33 in.	27 in.

These proposed new standards offer several distinct advantages compared to the current New York State standards (listed in the abstract):

1. Height adjustment costs will be minimized,

2. Barriers already installed to current standards will be within the new range,

3. Existing barriers already installed to current standards can accommodate at least two overlays, and those installed to the proposed new standards can accommodate at least one overlay before height adjustment is necessary,

4. These proposed heights appear to provide good protection against both underride and vaulting for the current fleet, and accommodate most vehicles now in service, including vans and light trucks, and

5. This proposal appears reasonable and defensible in terms of considerable crash test and in-service accident experience.

Because more definitive research results will not be available for some time, implementation of these standards at this time offers the potential of improving highway safety and reducing construction costs on R&P projects during the interim period. Further refinements to the proposed standards and tolerances can be made at the completion of the planned research, with little or no adverse effects caused by early implementation of this proposal.

B. <u>Traffic Barrier Performance Related to Vehicle Size and Type</u> (Transportation Research Record 1065 (1986), pp. 69-78, presented as a paper at the 65th Annual Meeting of the Transportation Research Board)

Data for this investigation was obtained from reported traffic accidents filed with the New York State Department of Motor Vehicles. It included data on 4698 traffic accidents occurring on state-maintained highways between July 1, 1982 and June 30, 1983. In 3302 of these accidents, the primary collision involved a traffic barrier. The data compiled contained information on personal injuries, vehicle damage and characteristics, barrier and highway characteristics, and various impact and vehicle trajectory parameters.

1. Abstract

Field investigations were completed at 3302 traffic barrier accident sites in New York State to determine the effects of various parameters on barrier performance. Information gathered included vehicle size and type, barrier type and rail height, and highway parameters. Performance was assessed in terms of occupant injuries, vehicle containment, and secondary collisions.

New York's traffic barriers resulted in lower occupant injury rates than roadside accidents in general, with modern barrier types resulting in fewer injuries than older barriers. Satisfactory vehicle containment was achieved in about 75 percent of the reported barrier accidents. Secondary collisions resulted in about 25 percent of all barrier accidents, primarily when the vehicle was not contained by the barrier. Secondary collisions with fixed objects were most common, followed by rollovers, but other vehicles or pedestrians were rarely involved. Injury rates were much higher when satisfactory containment was not achieved, or secondary collisions resulted.

Traffic barriers performed best for passenger cars, with somewhat reduced performance for vans and light trucks. Heavy trucks experienced about the same severe injury rates as passenger cars, but frequently penetrated traffic barriers and often were involved in secondary collisions. Injury rates in motorcycle accidents were very high. Traffic barriers performed best in collisions with mid-size passenger cars, followed by the smallest and then the largest passenger cars. The lower protection provided large cars appears related to more frequent barrier penetration and secondary collisions.

2. Discussion and Findings

The discussion portion of this paper dealt with performance of newer and older barriers. Barrier function, as defined by the post-impact trajectory of the vehicle, described how the barrier either met or failed to meet its primary purpose of preventing contact with the roadside hazard. Secondary collisions provided a second measure of how well the barrier performed this function. Barrier performance with respect to large passenger cars, vans and light trucks, large trucks, and small passenger cars was reviewed. Based on the results the following findings were listed:

1. Accidents involving traffic barriers on New York State highways resulted in lower injury rates than roadside accidents in general.

2. Traffic barriers then installed in New York State performed much better than older barriers in terms of occupant injury rates.

3. Severity of occupant injuries was closely related to vehicle damage for traffic barrier accidents examined in this study.

4. Satisfactory vehicle containment was achieved in over 75 percent of the traffic barrier accidents investigated in this study.

5. About 25 percent of the accidents investigated involved a secondary collision after the primary collision with the traffic barrier.

6. Fixed-object collisions were the most common second event, occurring in less than 18 percent of all accidents, followed by rollovers with less than 8 percent. Secondary collisions with other vehicles or pedestrians were extremely rare.

7. Injury rates were much higher for accidents involving lack of containment or secondary collisions.

8. Barriers performed best in accidents involving passenger cars, with reduced performance for vans and light trucks in terms of injury rates, containment, and secondary collisions.

9. Injury rates were very high for motorcycle accidents involving traffic barriers.

10. Barriers did not perform well with heavy trucks in terms of vehicle containment and secondary collisions. However, severe injury rates for large vehicles were about the same as for passenger cars, although non-severe injury rates were higher.

11. Traffic barriers generally performed best with passenger cars in the lower size and weight classes, with some reduction in performance for larger vehicles.

12. The relatively lower protection provided the largest passenger cars appears related to reduced vehicle containment and more frequent secondary events experienced by these vehicles.

13. Small cars experienced more rollovers following traffic barrier collisions, but this event was still relatively rare, resulting in only about 7 percent of collisions for the smallest vehicles.

14. Large passenger cars experienced more secondary collisions with fixed objects than smaller ones, involving 20 percent of all accidents for the largest cars.

C. Guiderail Performance (paper presented at the 1986 Annual Meeting of The New York State Transportation Engineers, Rochester, N.Y.)

Engineering Research is in the final stages of a traffic barrier accident study that has yielded some important data concerning guiderail performance. About 4000 reported barrier accidents occur on state-maintained highways each year -- about one for every mile of barrier. Unreported accident rates are five to ten times the reported ones.

Field investigations were conducted at 3302 accident sites upstate and on Long Island, with injuries, barrier penetration, and secondary collisions the primary measures of barrier performance. Barrier accidents were found to be more severe than all traffic accidents combined, but not as severe as all roadside accidents. Considering only passenger car impacts on modern barriers in good condition, injury severity was very low, even less than the average for all accidents. Barrier penetration and secondary collisions resulted in much higher injury severities, but penetration and secondary collisions were rare for midsection impacts on modern barriers in good condition. Older barrier systems and current ones in poor condition, however, experienced frequent penetration and secondary collisions, with high injury severities.

Injury rates on barrier terminals -- end sections -- were much higher than on midsections. This is related to design of terminals, which are not intended to prevent penetration, and lack of adequate clear recovery areas behind the terminals. Short barrier sections cannot shield roadside hazards, because they do not provide adequate midsection length to contain an errant vehicle safely. Barrier performance on limited-access highways was much better than on other rural highways. Generally, limited-access highways have newer barriers and better roadside clear areas, accounting for much of this difference.

These results suggest several areas where maintenance engineers can have a positive influence on traffic barrier management:

1. Although guiderail reduces the severity of roadside accidents, there are still 50 fatal and 2000 injury accidents every year involving guiderail on state highways. Many of these injuries and deaths can be prevented if properly designed and maintained barrier is provided where needed.

2. Maintenance engineers know their highway system, and can provide valuable input concerning guiderail management decisions. When new guiderail is installed, they can help ensure it is placed where most needed.

3. Old guiderail systems do not perform as well as new ones. Repairs to old barrier systems thus are less cost-effective than replacing damaged runs with modern barrier.

4. Short runs of barrier are generally ineffective, and are discouraged. This is especially true if short runs are used to provide delineation or access control. Other devices -- delineators and curbs -- are cheaper to install and maintain, and less dangerous when hit.

5. Because rural highways have the most old rail and most cluttered roadsides, they provide greatest potential for improvement. Limited-access highways generally have newer barriers and clearer roadsides, thus offering fewer candidates for barrier improvements.

6. Guiderail is the last-resort solution to roadside safety. Desirable alternatives are to remove the hazard (flatten slopes, remove trees, etc.) or reduce the hazard (install breakaway supports, etc.) In the long run, these alternatives cost less to maintain and are safer.

7. Guiderail condition has an important effect on performance. Modern traffic barriers may provide excellent protection to occupants of impacting vehicles, but even minor deficiencies in the barrier can adversely affect performance. It is thus important to maintain traffic barriers as near to as-built condition as possible.

D. Performance of Highway Traffic Barriers (paper presented at the 1986 ASCE Conference "Effectiveness of Highway Safety Improvements")

1. Abstract

This paper describes an investigation of traffic barrier performance in New York State. A one-year sample of all traffic-barrier accidents in the state was obtained from Department of Motor Vehicles files. Field investigations were completed on more than 3000 accidents to identify barrier and roadway features. This information was combined with vehicle and injury data, and accident descriptions. Barrier performance is discussed in terms of several evaluation criteria, including occupant injuries, barrier penetration, and secondary collisions. Effects of several variables are examined, including impact conditions, vehicle size and weight, and highway and barrier parameters. Injury severity was lower for traffic barrier accidents in general than for all roadside accidents. Considering only passenger car accidents involving modern barriers in good condition, injury severity was very low compared to other accident types.

2. Discussion and Summary

Highway traffic barriers are an important roadside safety resource. Modern barrier designs, properly installed and maintained, may reduce injury severity for passenger car occupants involved in roadside collisions. Traffic barrier collisions, in general, may be severe events, with more than one-tenth of the accidents investigated in this study resulting in a severe or fatal injury. However, within their design limitations, injury rates for modern traffic barriers were substantially lower than for all traffic accidents and all roadside accidents. Chances of injury increased significantly when the barrier failed to contain the impacting vehicle, and when a secondary collision occurred after initial barrier impact. Fortunately, both barrier penetration and secondary collisions were relatively rare for midsection impacts on modern barriers.

Traffic barriers are typically designed for passenger car impacts. Data from this study confirmed that best protection was provided for their occupants, but reasonably good protection was also observed for larger vehicles. Injury rates were generally lower for smaller passenger cars, and higher for the larger sizes. These higher rates for larger cars were associated with more frequent barrier penetration and secondary collisions.

Several highway parameters were examined to determine their effect on barrier performance. Apparent relationships to injury severity were noted for accident site character, roadway alignment, and both statutory and advisory speed limits. Generally, injury severity increased as alignment severity increased. This relationship appears to reflect increased impact severity -- especially impact angle -- that may be associated with severe geometric alignments. More barrier accidents occurred on rural highways than on limited-access facilities. The lower severity rates observed on limited- access facilities are attributed to the presence of newer barriers and improved roadside design on these highways. Conventional rural highways, on the other hand, have a higher concentration of older barriers, and much more restricted roadsides. The expected increase in injury severity with permitted speed was not observed in these data. Both statutory and advisory speed limits often serve as surrogate measures for other highway parameters. Roads with lower posted speeds frequently have more severe alignments, narrower and more cluttered roadsides, and older traffic barriers. These factors probably account for the lack of a clear-cut increase in injury severity with increasing speed limits.

Based on 3302 traffic barrier accidents investigated in this study, modern traffic barriers in New York State are generally providing good protection to occupants of the current vehicle fleet. However, barrier type and condition, and highway and roadside features appear to have a major influence on barrier performance.

E. Traffic Barrier Performance Related to Passenger Car Characteristics

(Special Report 87, March 1987, presented as a paper at the 1987 International Congress and Exposition of the Society of Automotive Engineers)

1. Abstract

Passenger cars have become smaller and lighter over the past two decades, and have lower, more aerodynamic frontal shapes. Traffic barriers, however, have changed little since current systems were developed in the 1960s. There is growing concern that changes in vehicle characteristics will adversely affect barrier performance, resulting in decreased protection for occupants of modern cars. This paper compares current vehicle frontal geometry to typical 1960s geometry. In addition, examples of barrier accidents are discussed in which vehicle characteristics contributed to severe results.

To determine how performance is affected by vehicle characteristics, a data base consisting of 3300 barrier accidents was compiled, covering the period from July 1982 through June 1983. This paper discusses effects of vehicle size, weight, and model year on accident severity. In addition, accident severity involving vehicle models with low frontal profiles was examined. Based on this analysis, it appears that better barrier performance is achieved for newer vehicles, and automobile size and weight do not substantially affect barrier performance. However, this accident sample included few current vehicles with low frontal profiles, and some of the concerns relating to such vehicles thus could not be examined.

2. Summary and Findings

Traffic barriers have been found to be effective in reducing severity of passenger car off-road accidents. However, barrier performance depends on vehicle characteristics, including size, model year, and frontal geometry. The downward trend in both bumper heights and hood heights has shifted concern over vehicle-barrier compatibility from barrier vaulting to underride. In the 1970s, vaulting was of sufficient concern that standard barrier heights were raised in New York State. By the mid-1980s, a lowering of hood and bumper heights, combined with occasional accidents involving underride, indicated a need to reduce barrier height. However, design of several models with very low hoods makes it impossible to provide good underride protection for all vehicles.

Based on examination of passenger car dimensions from the 1960s through the 1980s, and a large sample of traffic barrier accidents in New York State, the following findings can be stated:

1. Traffic barriers provide good protection for occupants of passenger vehicles on New York highways.

2. Traffic barriers perform better for newer passenger cars than for older ones.

3. After eliminating effects of model year, differences in barrier performance relating to passenger car size were small. Although some were statistically significant, they are not large enough to suggest a problem for any size group.

4. Vehicle-barrier incompatibility -- both high bumpers and low hoods -- has been identified as contributing to undesirable barrier performance in some barrier accidents.

5. Low hood heights popular on current vehicles cause concern over barrier underride. However, New York barrier accident statistics from 1982 and 1983 showed no adverse barrier performance for a subsample of vehicles with low hood heights.

F. Development of an Economic Model to Compare Median Barrier Costs (Research Report 138, February 1987) and Median Barrier Cost Analysis (Client Report 2, February 1987)

Existing warrants require installation of traffic barriers in narrow medians to prevent cross-over accidents on multi-lane highways. In high-volume urban situations, most often in New York City and on Long Island, light-post median barrier -- W-beam and box beam -- were generally not used because frequent accidents and resulting barrier damage made it virtually impossible for maintenance forces to keep barriers in operating condition. Further complicating the situation were resulting disruptions to traffic flow and safety hazards for both motorists and workers when narrow median widths required lane closure to accomplish repairs.

The normal choice for these situations thus was to specify either heavy-post blocked-out steel W-beam (MB-4S) or concrete median barrier (CMB). Although the MB-4S system offered lower first cost and improved impact protection for high-angle impacts, it too had the same drawbacks as light-post systems on narrow medians under heavy traffic. Thus, Departmental policy provided for use of

CMB where clearance between the barrier and pavement edge was less than 10 ft, free-flow speeds were 50 mph or higher, and the highway operated at or below Level-of-Service C (as defined in the Highway Capacity Manual) during average daily peak hours. For other situations, a steel barrier had to be used. This policy was based on high maintenance costs resulting from frequent repairs of steel barrier in these situations, coupled with the disruption to traffic flow and safety hazard caused by closing a lane to repair steel barrier.

Highways proposed for rehabilitation or reconstruction frequently warranted installation of median barrier where none existed, or where existing median had to be rebuilt. In addition, existing median barriers sometimes required extensive rehabilitation to bring them into compliance with current standards. Because of relatively high initial cost of CMB compared to MB-4S, cost-effectiveness of the Departmental policy was questioned by Department management. The Engineering Research and Development Bureau was thus requested to perform an economic analysis to determine whether the policy was justified.

The analysis was intended to answer two specific questions concerning median barrier installation:

1. Should existing MB-4S median barrier in deteriorated condition be repaired, replaced in kind, or replaced with CMB?

2. Given the decision to install a new median barrier on an urban expressway, should MB-4S or CMB be selected?

1. Abstract

The New York State Department of Transportation specifies concrete safety-shaped barrier in narrow medians on high-volume urban expressways, where frequent impact repairs would result in traffic delays and high repair costs if steel barriers were used. Because of higher initial cost of concrete barrier, its cost-effectiveness has been questioned. A model was developed to compare total costs of concrete safety-shaped and heavy-post blocked-out W-beam median barriers. This model considers construction, repair, and user accident costs, using input values selected from construction and repair costs, and accident data compiled by New York and others. It was used to determine which barrier is the better economic choice for various situations. A manual worksheet and computer spreadsheet solutions were developed to permit designers to solve the model for other highway situations, and to use alternative values for the input parameters. A sensitivity analysis was performed to determine effects of the various input parameters on the break-even traffic volume at which the two systems provide equal cost. Because it has a higher initial cost but lower repair cost, concrete barrier is the more economical at higher traffic volumes.

2. Summary

The median barrier cost analysis worksheet was developed to provide designers an easy method to compare costs of blocked-out W-beam and concrete-safety-shape median barriers. To use this worksheet, the designer must have an IBM-compatible microcomputer, a copy of the LOTUS 1-2-3 Release 1A software, and a copy of the worksheet diskette. Client Report 2 gives

operating instructions for this spreadsheet solution. Values on the worksheet fall into three categories: 1) those input by the designer, 2) input values locked into the worksheet, and 3) output values computed by the program using the input values and formulas built into the worksheet.

G. Comparative Analysis of Box-Beam and Heavy-Post W-Beam Traffic Barriers (Client Report 15, June 1987)

The Facilities Design Division proposed replacing box-beam guiderail with heavy-post blocked-out W-beam guiderail. The latter would be transitioned to light-post W-beam guiderail where available deflection distance permits use of a more flexible barrier, and at barrier terminals to permit continued use of the standard W-beam terminal.

They raised several questions concerning impact of these proposed changes on highway safety. Using the large database on traffic barrier performance compiled for this study (Research Project 180-1), this report was prepared to discuss relative performance of these barriers. Based on the information available, the following conclusions appear warranted:

1. The transition from light-to-heavy post W-beam was shown to perform satisfactorily in full-scale tests, and is suitable for field installation. Like any new barrier feature, it should be monitored to confirm that its in-service performance is satisfactory.

2. All W-beam and box-beam terminals represent some degree of compromise. Although the light-post W-beam terminal has not been shown to meet all criteria in NCHRP Report 230, it is considered an acceptable choice when it can be flared away from the pavement.

3. Although the sample of heavy post W-beam was small, box-beam and heavy-post W-beam barriers appeared to perform about the same in terms of injury severity, vehicle containment, secondary collisions, and vehicle damage, based on data collected in Project 180-1.

4. Based on data collected in this study, it is difficult to assess the total impact rate on the various barrier systems, including "drive-aways." Although the systems may differ substantially, the sample for heavy post W-beam is too small to assess.

5. A change from box-beam to heavy-post W-beam barrier does not appear to involve any adverse trade-offs in terms of highway safety, based on data currently available.

6. A detailed cost analysis examining effects of length-of-run and maintenance costs is recommended to determine the most economical barrier for a given situation, based on the assumption of equal impact performance.

H. Effects of Curbs on Traffic Barrier Performance (Client Report 33, November 1988)

NCHRP Report 150 (Effect of Curb Geometry and Location on Vehicle Behavior) established that commonly used curb types have pronounced effects on vertical trajectory of passenger cars impacting those curbs. Specifically, the vehicle rises vertically as it crosses the curb line, with height of rise of the vehicle's center of gravity and front bumper varying with impact conditions, type of curb, and lateral distance traveled behind the curb. Because height change of the front bumper is several inches for some impact conditions, this aroused concern for performance of traffic barriers placed behind curbs. Eventually, recommendations were developed in national standards and guidelines completely precluding use of curbs in front of traffic barriers. This Department adopted a more moderate approach -- Chapter 10 of the Design Manual precludes installation of barrier from 1 to 10 ft behind a curb for highways with speeds of 50 mph or more. This guideline was recently reaffirmed by Engineering Instruction 88-28, which adds the Design Manual note to traffic barrier standard sheets, but without the low-speed exclusion.

In the summer of 1988, the Facilities Design Division requested the Engineering Research and Development Bureau to examine this guideline in light of data collected under Research Project 180-1.

1. Discussion and Recommendations

Based on the analysis, a substantial number of traffic barriers are found within 1 to 10 ft behind curb -- the zone excluded by the guidelines. Examination of NCHRP Report 150 bumper-trajectory data indicates little more risk in increasing the lower limit to 1.5 or 2 ft. However, the upper limit of 10 ft entails risks of both vaulting and underride, and it does not appear feasible to define a reasonable upper limit to reduce these risks. On the other hand, analysis of 330 curb-involved accidents shows no adverse effects on barrier performance attributable to placement behind a curb, regardless of offset or curb type. Rather than adversely affecting barrier performance, it appeared that performance was slightly better for barrier placed behind a curb. For limited-access, full-speed highways, where most of the curb was found, accidents involving a curb in front of the barrier had significantly fewer serious and moderate injuries, and non-mountable curbs resulted in more frequent vehicle redirection and fewer secondary collisions than mountable curb or no curb.

From a design standpoint, relaxation of restrictions on curb-barrier placement would provide greater flexibility in terms of drainage control, channelization of traffic, pedestrian protection, aesthetics, and other design considerations. However, existing national policies and guidelines advise against any use of curb on high-speed roadways, and even more strongly advise against barrier placement behind a curb. Any effort to relax curb-barrier policy would thus probably encounter resistance from FHWA. In addition, tort liability exposure for any future accidents involving barrier placed counter to accepted national guidelines must be considered.

Based on this analysis and discussion, the following options are offered for consideration:

1. Both the accident data and NCHRP bumper-trajectory analyses support increasing the lower limit somewhat. Thus raising this limit to about 2 ft is recommended, assuming that this increase provides some advantages in terms of design flexibility.

2. At this time, it does not appear possible to select an improved upper limit. If the upper limit of 10 ft is not presenting design difficulties, the safest option appears to leave it unchanged.

3. If any design considerations would benefit from reduction of the upper limit, additional analysis is needed to select a limit that balances the risk between vaulting and underride. Barrier height relative to the curb top must also be selected. Depending on the magnitude of this problem, it may be worth considering this subject for regional or national research programs, rather than addressing it at the state level.

III. BARRIER HEIGHT STANDARDS AND TOLERANCES

In 1983, the Engineering Research and Development Bureau recommended interim height standards and tolerances for light-post traffic barriers (4) based on several factors, including:

1. The then-current New York and AASHTO height standards and tolerances,
2. A review of full-scale barrier test data,
3. New York State barrier accident experience, and
4. Geometric characteristics of 1983 model vehicles.

Height recommendations, based on the analysis detailed in Research Report 111, were as follows:

Cable guiderail	27 ± 3 in.,
Box-beam guiderail and median barrier	27 ± 3 in.,
W-beam guiderail and median barrier	30 ± 3 in.

This research project was then initiated, representing a large-scale effort to examine in-service performance of traffic barriers and relate accident severity to mounting height and other factors. Department of Motor Vehicles computerized and hard-copy accident reports were reviewed as were Department of Transportation records, and on-site inspections made to obtain highway and barrier information. Complete data were obtained for about 3300 accidents that occurred between July 1, 1982 and June 30, 1983. Barrier height measurements were made at about 1700 accident sites involving light-post barriers. These height measurements occurred 1 to 2 years after the accidents and in most cases after the barrier had been repaired. However, the sample of height measurements was sufficient to establish that height at the time of the accident was defined within about ±2 in. with 95-percent confidence. The actual sample of accident sites where height measurements were taken can be categorized as follows:

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Barrier Type	Total Accidents	Passenger Car Accidents
Cable guiderail	427	356
Cable median barrier	16	15
W-beam guiderail	306	252
W-beam median barrier	46	42
Box-beam guiderail	623	530
Box-beam median barrier	308	281

Three primary evaluation criteria were used to assess barrier performance -- occupant injuries, post-impact vehicle trajectory, and secondary collisions. Summarized accident data for the six barrier types, relating height measurements to these three evaluation criteria are presented in Tables 1 through 9. After extensive analysis, very few significant trends could be identified relating barrier height to performance. In most cases, evaluation criteria were quite insensitive to height, at least over the range of heights most frequently encountered. In a few cases some apparent trends appeared, but their statistical significance was low. Even though the total sample of light-post barrier accidents exceeded 1700, most heights measured were clustered within a narrow range near the specified heights. It thus is impossible to assess performance at heights more than a few inches from the current standards.

Accident severity was determined based on worst injury to a vehicle occupant. Injury severity for each occupant involved in the accident was included in the motor vehicle record. Police accident reports record injury data for three parameters -- location of most severe physical complaint, type of physical complaint, and victim's physical and emotional status -- each according to a subjective rating scale. Motorist reports provide a narrative description of injuries. This information is then used to classify injury severity at the time the record is coded by the Department of Motor Vehicles. The most severe non-fatal types ("A" injuries) include severe lacerations, broken or distorted limbs, skull fractures, and other serious injuries. Abrasions, lacerations, and lumps to the head are classed as "B" injuries, while "C" injuries are limited to momentary unconsciousness, limping, nausea, hysteria, and complaint of pain with no visible injury.

No injury level was designated on nearly one-third of the records examined. Because state law requires reporting injuries, and because most accident reports were filed by police agencies, it was assumed that records with no specific report of injuries actually represented accidents without them. Although a few very minor injuries may have gone undetected, it seems unlikely that many, if any, severe injuries went unreported.

Tables 1, 2, and 3 present accident and injury data for cable, box-beam, and w-beam barrier systems, respectively. Sample sizes for cable and w-beam median barrier are much smaller than those for other barrier systems. This reflects their usage and thus the exposure of the different median barrier systems.

The percentages of fatal and Type A injuries in accidents involving cable guiderail are basically the same for barrier heights between 24 and 33 in. (Table

Table 1. Cable barrier mounting height vs injuries.

Barrier Height, in.	Total Accidents	Severity of Injury*					
		Fatal + A		B + C		No Injury	
		Total	%	Total	%	Total	%
GUIDERAIL							
≤21	2	0	0.0	2	100.0	0	0.0
>21≤22	3	0	0.0	3	100.0	0	0.0
>22≤23	5	0	0.0	3	60.0	2	40.0
>23≤24	13	3	23.0	6	46.0	4	31.0
>24≤25	16	2	12.5	6	37.5	8	50.0
>25≤26	31	3	9.7	12	38.7	16	51.6
>26≤27	23	2	8.7	9	39.1	12	52.2
>27≤28	50	4	8.0	21	42.0	25	50.0
>28≤29	70	7	10.0	31	44.3	32	45.7
>29≤30	100	10	10.0	49	49.0	41	41.0
>30≤31	82	5	6.1	26	31.7	51	62.2
>31≤32	12	1	4.6	7	31.8	14	63.6
>32≤33	8	1	12.5	2	50.0	5	62.5
>33	2	0	0.0	1	50.0	1	50.0
Total	427	38	8.9	178	41.7	211	49.4
MEDIAN BARRIER							
≤24	0	0	-	0	-	0	-
>24≤25	0	0	-	0	-	0	-
>25≤26	1	0	0.0	1	100.0	0	0.0
>26≤27	0	0	-	0	-	0	-
>27≤28	0	0	-	0	-	0	-
>28≤29	0	0	-	0	-	0	-
>29≤30	6	1	16.7	4	66.6	1	16.7
>30≤31	8	0	0.0	5	62.5	3	37.5
>31≤32	1	0	0.0	0	0.0	1	100.0
>32≤33	0	0	-	0	-	0	-
>33	0	0	-	0	-	0	-
Total	16	1	6.3	10	62.5	5	31.2

*Injury Types: A = severe lacerations, broken or distorted limbs, skull fractures, other serious injuries, B = abrasions, lacerations, lumps to the head, C = momentary unconsciousness, limping, nausea, hysteria, complaints or pain with no visible injury.

Table 2. Box-beam barrier mounting height vs injuries.

Barrier Height, in.	Total Accidents	Severity of Injury*					
		Fatal + A		B + C		No Injury	
		Total	%	Total	%	Total	%
GUIDERAIL							
≤21	2	0	0.0	2	100.0	0	0.0
>21≤22	6	1	16.7	4	66.6	1	16.7
>22≤23	6	1	16.7	3	50.0	2	33.3
>23≤24	28	3	10.7	18	64.3	7	25.0
>24≤25	36	3	8.3	20	55.6	13	36.1
>25≤26	45	4	8.9	25	55.6	16	35.5
>26≤27	49	8	16.3	27	55.1	14	28.6
>27≤28	59	5	8.5	36	61.0	18	30.5
>28≤29	106	11	10.4	60	56.6	35	33.0
>29≤30	140	13	9.3	75	53.6	52	37.1
>30≤31	83	5	6.0	48	57.8	30	36.2
>31≤32	33	6	18.2	21	63.6	6	18.2
>32≤33	13	1	7.7	4	30.8	8	61.5
>33	17	1	5.9	10	58.8	6	35.3
Total	623	62	9.9	353	56.7	208	33.4
MEDIAN BARRIER							
≤21	10	1	10.0	4	40.0	5	50.0
>21≤22	0	0	-	0	-	0	-
>22≤23	0	0	-	0	-	0	-
>23≤24	5	1	20.0	2	40.0	2	40.0
>24≤25	16	0	0.0	11	68.8	5	31.2
>25≤26	18	2	11.1	8	44.4	8	44.5
>26≤27	55	6	10.9	28	50.9	21	30.2
>27≤28	51	4	7.8	31	60.8	16	31.4
>28≤29	49	8	16.3	27	55.1	14	28.6
>29≤30	42	5	11.9	22	52.4	15	35.7
>30≤31	32	1	3.1	21	65.6	10	31.3
>31≤32	17	1	5.9	9	52.9	7	41.2
>32≤33	8	0	0.0	6	75.0	2	25.0
>33	5	1	20.0	2	40.0	2	40.0
Total	308	30	9.8	171	55.5	107	34.7

*Injury Types: A = severe lacerations, broken or distorted limbs, skull fractures, other serious injuries, B = abrasions, lacerations, lumps to the head, C = momentary unconsciousness, limping, nausea, hysteria, complaints or pain with no visible injury.

Table 3. W-beam barrier mounting height vs injuries.

Barrier Height, in.	Total Accidents	Severity of Injury* Fatal + A Total	%	B + C Total	%	No Injury Total	%
GUIDERAIL							
≤21	1	0	0.0	0	0.0	1	100.0
>21≤22	0	0	-	0	-	0	-
>22≤23	2	0	0.0	2	100.0	0	0.0
>23≤24	7	1	14.3	5	71.4	1	14.3
>24≤25	13	4	30.8	5	38.4	4	30.8
>25≤26	19	2	10.5	11	57.9	6	31.6
>26≤27	23	2	8.7	11	47.8	10	43.5
>27≤28	17	2	11.8	9	52.9	6	35.3
>28≤29	17	4	23.5	8	47.1	5	29.5
>29≤30	32	8	25.0	12	37.5	12	37.5
>30≤31	41	3	7.3	20	48.8	18	43.9
>31≤32	57	4	7.0	24	42.1	29	50.9
>32≤33	46	3	6.5	20	43.5	23	50.0
>33	31	3	9.7	13	41.9	15	48.4
Total	306	36	11.8	140	45.7	130	42.5
MEDIAN BARRIER							
≤23	0	0	-	0	-	0	-
>23≤24	0	0	-	0	-	0	-
>24≤25	1	0	0.0	1	100.0	0	0.0
>25≤26	1	0	0.0	1	100.0	0	0.0
>26≤27	5	0	0.0	2	40.0	3	60.0
>27≤28	1	1	100.0	0	0.0	0	0.0
>28≤29	0	0	-	0	-	0	-
>29≤30	2	0	0.0	1	50.0	1	50.0
>30≤31	5	0	0.0	1	20.0	4	80.0
>31≤32	4	1	25.0	0	0.0	3	75.0
>32≤33	12	2	16.7	4	33.3	6	50.0
>33	15	1	6.7	8	53.3	6	40.0
Total	46	5	10.9	18	39.1	23	50.0

*Injury Types: A = severe lacerations, broken or distorted limbs, skull fractures, other serious injuries, B = abrasions, lacerations, lumps to the head, C = momentary unconsciousness, limping, nausea, hysteria, complaints or pain with no visible injury.

Table 4. Cable barrier mounting height vs vehicle trajectory.

Barrier Height, in.	Total Accidents	Vehicle Trajectory: Number Redirected Total	%	Number Stopped Total	%	Number Contained Total	%
GUIDERAIL							
≤21	2	1	50.0	0	0.0	1	50.0
>21≤22	3	3	100.0	0	0.0	3	100.0
>22≤23	5	3	60.0	1	20.0	4	80.0
>23≤24	13	7	53.9	0	0.0	7	53.9
>24≤25	16	12	75.0	2	12.5	14	87.5
>25≤26	31	23	74.2	2	6.4	25	80.7
>26≤27	23	16	69.6	3	13.0	19	82.6
>27≤28	50	31	62.0	8	16.0	39	78.0
>28≤29	70	53	75.7	3	4.3	56	80.0
>29≤30	100	57	57.0	23	23.0	80	80.0
>30≤31	82	46	56.1	21	25.6	67	81.7
>31≤32	22	13	59.1	7	31.8	20	90.9
>32≤33	8	5	62.5	2	25.0	7	87.5
>33	2	1	50.0	0	0.0	1	50.0
Total	427	271	63.5	72	16.8	343	80.3
MEDIAN BARRIER							
≤24	0	0	-	0	-	0	-
>24≤25	0	0	-	0	-	0	-
>25≤26	1	1	100.0	0	0.0	1	100.0
>26≤27	0	0	-	0	-	0	-
>27≤28	0	0	-	0	-	0	-
>28≤29	0	0	-	0	-	0	-
>29≤30	6	6	100.0	0	0.0	6	100.0
>30≤31	8	7	87.5	0	0.0	7	87.5
>31≤32	1	1	100.0	0	0.0	1	100.0
>32≤33	0	0	-	0	-	0	-
>33	0	0	-	0	-	0	-
Total	16	15	93.8	0	0.0	15	93.8

Table 5. Box-beam barrier mounting height vs. vehicle trajectory.

Barrier Height, in.	Total Accidents	Number Redirected Total	Number Redirected %	Number Stopped Total	Number Stopped %	Number Contained Total	Number Contained %
GUIDERAIL							
≤21	2	2	100.0	0	0.0	2	100.0
>21≤22	6	5	83.3	0	0.0	5	83.3
>22≤23	6	5	83.3	0	0.0	5	83.3
>23≤24	28	21	75.0	3	10.7	24	85.7
>24≤25	36	33	91.7	2	5.6	35	97.2
>25≤26	45	43	95.6	2	4.4	45	100.0
>26≤27	49	36	73.5	9	18.4	45	91.8
>27≤28	59	49	83.1	9	15.3	58	98.3
>28≤29	106	91	85.9	10	9.4	101	95.3
>29≤30	140	118	84.3	19	13.6	137	97.9
>30≤31	83	66	79.5	14	16.9	80	96.4
>31≤32	33	30	90.9	3	9.1	33	100.0
>32≤33	13	11	84.6	2	15.4	13	100.0
>33	17	13	76.5	4	23.5	17	100.0
Total	623	523	83.9	77	12.3	600	96.3
MEDIAN BARRIER							
≤21	10	9	90.0	0	0.0	9	90.0
>21≤22	0	0	-	0	-	0	-
>22≤23	0	0	-	0	-	0	-
>23≤24	5	4	80.0	1	20.0	5	100.0
>24≤25	16	16	100.0	0	0.0	16	100.0
>25≤26	18	16	88.9	2	11.1	18	100.0
>26≤27	55	48	87.3	5	9.1	53	96.4
>27≤28	51	46	90.2	4	7.8	50	98.0
>28≤29	49	45	91.8	3	6.1	48	98.0
>29≤30	42	42	100.0	0	0.0	42	100.0
>30≤31	32	26	81.3	6	18.8	32	100.0
>31≤32	17	16	94.1	0	0.0	16	94.1
>32≤33	8	6	75.0	1	12.5	7	87.5
>33	5	5	100.0	0	0.0	5	100.0
Total	308	279	90.6	22	7.1	301	97.7

Table 6. W-beam barrier mounting height vs vehicle trajectory.

Barrier Height, in.	Total Accidents	Vehicle Trajectory: Number Redirected Total	%	Number Stopped Total	%	Number Contained Total	%
GUIDERAIL							
≤21	1	1	100.0	0	0.0	1	100.0
>21≤22	0	0	-	0	-	0	-
>22≤23	2	1	50.0	1	50.0	2	100.0
>23≤24	7	7	100.0	0	0.0	7	100.0
>24≤25	13	10	76.9	1	7.7	11	84.6
>25≤26	19	16	84.2	1	5.3	17	89.5
>26≤27	23	18	78.3	2	8.7	20	87.0
>27≤28	17	14	82.4	1	5.9	15	88.2
>28≤29	17	13	76.5	2	11.8	15	88.2
>29≤30	32	27	84.4	1	3.1	28	87.5
>30≤31	41	37	90.2	1	2.4	38	92.7
>31≤32	57	45	79.0	3	5.3	48	84.2
>32≤33	46	40	87.0	1	2.2	41	89.1
>33	31	26	83.9	3	9.7	29	93.6
Total	306	255	83.3	17	5.6	272	88.9
MEDIAN BARRIER							
≤23	0	0	-	0	-	0	-
>23≤24	0	0	-	0	-	0	-
>24≤25	1	1	100.0	0	0	1	100.0
>25≤26	1	1	100.0	0	0	1	100.0
>26≤27	5	5	100.0	0	0	5	100.0
>27≤28	1	0	0.0	1	100.0	1	100.0
>28≤29	0	0	-	0	-	0	-
>29≤30	2	2	100.0	0	0	2	100.0
>30≤31	5	4	80.0	0	0	4	80.0
>31≤32	4	4	100.0	0	0	4	100.0
>32≤33	12	11	91.7	1	8.3	12	100.0
>33	15	14	93.3	1	6.7	15	100.0
Total	46	42	91.3	3	6.5	45	97.8

Table 7. Cable barrier mounting height vs secondary events.

Barrier Height, in.	Total Accidents	Secondary Events: Number Overturned Total	%	Number Hit Fixed Object Total	%	No Secondary Event Total	%
GUIDERAIL							
≤21	2	0	0.0	2	100.0	0	0.0
>21≤22	3	0	0.0	1	33.3	2	66.7
>22≤23	5	0	0.0	1	20.0	4	80.0
>23≤24	13	3	23.1	4	30.8	5	38.5
>24≤25	16	1	6.3	3	18.8	12	75.0
>25≤26	31	2	6.4	4	12.9	25	80.7
>26≤27	23	3	13.0	3	13.0	17	73.9
>27≤28	50	5	10.0	13	26.0	32	64.0
>28≤29	70	8	11.4	8	11.4	53	75.7
>29≤30	100	13	13.0	16	16.0	70	70.0
>30≤31	82	3	3.7	17	20.7	60	73.1
>31≤32	22	1	4.6	5	22.7	15	68.2
>32≤33	8	0	0.0	0	0.0	8	100.0
>33	2	0	0.0	1	50.0	1	50.0
Total	427	39	9.1	78	18.3	304	71.2
MEDIAN BARRIER							
≤24	0	0	-	0	-	0	-
>24≤25	0	0	-	0	-	0	-
>25≤26	1	0	0.0	0	0.0	1	100.0
>26≤27	0	0	-	0	-	0	-
>27≤28	0	0	-	0	-	0	-
>28≤29	0	0	-	0	-	0	-
>29≤30	6	0	0.0	0	0.0	6	100.0
>30≤31	8	1	12.5	0	0.0	7	87.5
>31≤32	1	0	0.0	0	0.0	1	100.0
>32≤33	0	0	-	0	-	0	-
>33	0	0	-	0	-	0	-
Total	16	1	6.2	0	0.0	15	93.8

Table 8. Box-beam barrier mounting height vs secondary events.

Barrier Height, in.	Total Accidents	Secondary Events					
		Number Overturned		Number Hit Fixed Object		No Secondary Event	
		Total	%	Total	%	Total	%
GUIDERAIL							
≤21	2	0	0.0	0	0.0	2	100.0
>21≤22	6	1	16.7	0	0.0	5	83.3
>22≤23	6	0	0.0	1	16.7	5	83.3
>23≤24	28	1	3.6	5	17.8	22	78.6
>24≤25	36	1	2.8	6	16.7	28	77.8
>25≤26	45	4	8.9	8	17.8	33	73.3
>26≤27	49	2	4.1	8	16.3	39	79.6
>27≤28	59	1	1.7	12	20.3	46	78.0
>28≤29	106	3	2.8	28	26.4	74	69.8
>29≤30	140	8	5.7	15	10.7	115	82.1
>30≤31	83	2	2.4	12	14.5	69	83.1
>31≤32	33	3	9.1	4	12.1	26	78.8
>32≤33	13	0	0.0	1	7.7	12	92.3
>33	17	1	5.9	4	23.5	12	70.6
Total	623	27	4.3	104	16.7	488	78.3
MEDIAN BARRIER							
≤21	10	0	0.0	2	20.0	8	80.0
>21≤22	0	0	-	0	-	0	-
>22≤23	0	0	-	0	-	0	-
>23≤24	5	0	0.0	1	20.0	4	80.0
>24≤25	16	0	0.0	1	6.2	15	93.8
>25≤26	18	0	0.0	4	22.2	14	77.8
>26≤27	55	1	1.8	4	7.3	50	90.9
>27≤28	51	0	0.0	5	9.8	46	90.2
>28≤29	49	1	2.0	5	10.2	42	85.7
>29≤30	42	0	0.0	8	19.0	34	81.0
>30≤31	32	3	9.4	2	6.2	27	84.4
>31≤32	17	2	11.8	1	5.9	14	82.3
>32≤33	8	0	0.0	0	0.0	8	100.0
>33	5	1	20.0	0	0.0	4	80.0
Total	308	8	2.6	33	10.7	266	86.4

Table 9. W-beam barrier mounting height vs secondary events.

Barrier Height, in.	Total Accidents	Secondary Events: Number Overturned Total	%	Number Hit Fixed Object Total	%	No Secondary Event Total	%
GUIDERAIL							
≤21	1	0	0.0	0	0.0	1	100.0
>21≤22	0	0	-	0	-	0	-
>22≤23	2	1	50.0	0	0.0	1	50.0
>23≤24	7	0	0.0	2	20.6	5	71.4
>24≤25	13	0	0.0	4	30.8	7	53.9
>25≤26	19	1	5.3	5	26.3	13	68.4
>26≤27	23	0	0.0	10	43.5	13	56.5
>27≤28	17	2	11.8	1	5.9	14	82.3
>28≤29	17	3	12.7	5	29.4	9	52.9
>29≤30	32	1	3.1	7	21.9	24	75.0
>30≤31	41	6	14.6	4	9.8	30	73.2
>31≤32	57	7	12.3	8	14.0	41	71.9
>32≤33	46	4	8.7	8	17.4	34	73.9
>33	31	2	6.5	5	16.1	24	77.4
Total	306	27	8.8	59	19.3	216	70.6
MEDIAN BARRIER							
≤23	0	0	-	0	-	0	-
>23≤24	0	0	-	0	-	0	-
>24≤25	1	0	0.0	0	0.0	1	100.0
>25≤26	1	0	0.0	0	0.0	1	100.0
>26≤27	5	0	0.0	1	20.0	4	80.0
>27≤28	1	0	0.0	0	0.0	1	100.0
>28≤29	0	0	-	0	-	0	-
>29≤30	2	0	0.0	0	0.0	2	100.0
>30≤31	5	0	0.0	0	0.0	5	100.0
>31≤32	4	0	0.0	0	0.0	4	100.0
>32≤33	12	0	0.0	0	0.0	12	100.0
>33	15	0	0.0	1	6.7	14	93.3
Total	46	0	0.0	2	4.3	44	95.7

1). In addition, accidents within this range in which no injuries were reported exceeded 50 percent on the average. Accidents involving box-beam guiderail differed little in percentage of fatal and Type A injuries over the range of the data (Table 2). About one-third of the accidents involving box-beam barriers with heights between 24 and 30 in. reported no injuries. Accident data involving w-beam guiderail at heights between 24 and 25 in. and between 28 and 30 in. seem to indicate a higher percentage of fatal and Type A injuries than for other heights (Table 3). Sample sizes for W-beam guiderail with mounting heights of 24 to 25 in. and 28 to 29 in. are small and the data thus may be misleading. Although there are 32 accidents on barriers 29 to 30 in. high, the percentage of fatal and Type A injuries appears greater than for barriers slightly higher or for those a few inches lower. Nearly half the accidents having barriers with heights between 27 and 33 in. reported no injuries.

There is little difference in percentage of fatal and Type A injuries for the various heights of box-beam median barrier accidents (Table 2) included in the data. Sample sizes for accidents involving cable (Table 1) and W-beam median barrier (Table 3) were too small to determine any trends. Thirty-four percent of accidents involving box-beam median barrier with heights between 24 and 30 in. reported no injuries.

Tables 4, 5, and 6 cover vehicle trajectories in these accidents by presenting data concerning numbers of vehicles that were redirected, stopped, and "contained." A vehicle was considered contained if it was either redirected or stopped. The difference between the number contained and total number of accidents thus is the number of vehicles that penetrated the barrier. High containment percentages consequently are desirable. For cable guiderail heights between 24 and 33 in., about four of every five vehicles involved in accidents were contained (Table 4). However, the percentage of vehicles redirected drops about 10 to 20 percent when mounting heights exceed 29 in. Because deceleration forces are less when a vehicle is redirected rather than stopped, this drop is of concern. Data on accidents involving box-beam guiderail (Table 5) reveal that higher percentages of containment were realized at almost every height for which data were obtained. Most containment percentages were over 90 percent. In addition, percentages of vehicles redirected were higher than comparable percentages from cable guiderail data.

The data did not indicate any one barrier height to be better than another for either redirecting or containing a vehicle. In accidents involving W-beam guiderail (Table 6) the percentage of vehicles contained was higher than with cable guiderail, but less than with box-beam. Again, performance did not indicate an optimum mounting height for redirection or containment.

As with accident severity, accident sample sizes involving cable or W-beam median barrier are too small to be of help. The data from accidents involving box-beam median barriers (Table 5) show results similar to performance of box-beam guiderail. Percentage of vehicles contained was about the same, while that for vehicles redirected was slightly higher for median barrier. The data did not indicate an optimum mounting height to maximize vehicle redirection or containment.

Tables 7 through 9 give data on performance of various barrier systems with respect to occurrence of secondary events versus mounting heights. These events concern the number of vehicles for each mounting height that overturned after hitting the guiderail and those that struck a fixed object after hitting the guiderail. Also listed are accidents having no secondary event. The numbers are minimums because some data on secondary events were missing.

From a performance viewpoint it is desirable not to have a secondary event. Better performance thus occurs when the no-secondary-event percentage is highest. In accidents involving cable guiderail (Table 7) no optimum height appears where no secondary events occurred. Accidents involving box-beam guiderail had fewer secondary events, but no apparent optimum height (Table 8). Accidents involving W-beam guiderail (Table 9) with mounting heights 27 in. and higher appear to have been slightly less serious than those with the beam mounted lower.

The only median barrier involved in a sufficient number of accidents to provide large sample sizes for many of the mounting heights was the box-beam. Although over four of five accidents had no second event, there still was no optimum mounting height indicated (Table 8).

Thus, these accident data did not identify a clear optimum range of rail heights, but were useful in evaluating a range of heights selected using other data sources. Research Report 111 had earlier recommended center-of-rail heights of 24 in. based on vehicle geometric characteristics, and these heights have been further evaluated through full-scale crash tests. In all, 12 tests on light-post barriers were completed at Southwest Research Institute under NCHRP Project 22-4, and two more cable guiderail tests were conducted by the Engineering Research and Development Bureau in 1985. With one possible exception, where a high center-of gravity van rolled over during a W-beam impact, these indicated that light-post barriers provide good redirection and tend to reduce undesirable effects of partial rail underride when center-of-rail heights were set at 24 in. The full-scale tests thus agree with values based on vehicle frontal geometries as recommended in Research Report 111.

As already noted, accident data analyzed in this study were from accidents that occurred between July 1, 1982 and June 30, 1983. Most vehicles involved were of pre-1980 vintage. Low-frontal geometry became increasingly common after 1980. The result is a dramatic change in frontal geometry from vehicles represented in the accident data to those that have since become more common in the current highway fleet.

Based on information from this study, it is anticipated that barrier underride will increase as the number of low-frontal geometry vehicles increase. This suggests that barrier heights should be adjusted downward from those specified in 1982 and 1983.

Accident data and full-scale test results confirm that center-of-rail heights of 24 in. perform about as well for larger and older vehicles as do the 27-in. center-of-rail heights specified in 1982-1983. A 3-in. drop in rail heights to accommodate lower frontal geometry of newer vehicles thus will not penalize older, larger vehicles.

Based on the information presented here and in other interim reports on this study, the following conclusions appear warranted:

1. Based on barrier performance as interpreted from accident data, no one optimum mounting height emerges for any barrier system examined in this study.

2. For cable guiderail, injuries were insensitive to rail heights over 24 in. Vehicle trajectory and secondary collisions improved somewhat in the 24- to 29-in. range. Above 29 in., a significant increase was noted in adverse vehicle trajectories.

3. For box-beam guiderail, a higher percentage of vehicles was contained when the barrier was 24 in. or higher. Performance in terms of injuries and secondary collisions was relatively unaffected for heights of 24 to 30 in.

4. For W-beam guiderail, although injury rates appear somewhat greater for heights below 30 in., sample size in most categories is small. This barrier had high redirection and containment rates at all heights above 23 in. It appeared more likely that a secondary event might occur at barrier heights under 27 in., but sample sizes in this range are small.

5. For cable and W-beam median barriers, because of their limited use their exposure to possible accidents was limited, and sample sizes thus were too small to assess performance.

6. For box-beam median barrier, although sample sizes were small, injury rates were essentially uniform for those 23 in. or higher. Redirection and containment rates were also high. Performance with respect to secondary events was essentially uniform for all heights within the range of the data, which indicated that few secondary events had occurred.

7. Frontal geometry of vehicles built and sold since 1983 for many makes and models is lower than that of those composing the fleet at the time the accident data were collected. There thus is concern that accidents resulting in barrier underride will increase unless barrier heights specified in the early 1980s are reduced.

Based on these conclusions, the following recommendations were made:

1. Set standard center-of-rail heights at 24 in. for all light-post barriers. This results in top-of-rail heights of 27 in. for cable and box-beam systems and 30 in. for W-beam systems.

2. Permit a construction tolerance of $\pm 1/4$ in.

3. Set a lower limit for center-of-rail height of 21 in. for all light-post barriers, and an upper limit of 27 in. Within this range, existing barriers will not require adjustment during highway-improvement projects.

4. For barriers outside the range of 24 ± 3 in., the impact of adjusting rail height should be examined on a case-by-case basis. Factors to be considered include traffic volumes; accident histories; traffic speeds;

roadway geometry; barrier type, condition, and height; projected future accident experience; and cost of adjusting height.

These recommendations have been implemented except for those involving median barrier applications.

REFERENCES

1. Van Zweden, J. and Bryden, J. E. In-Service Performance of Highway Barriers. Research Report 51, Engineering Research and Development Bureau, New York State Department of Transportation, July 1977.

2. Carlson, R. D., Allison, J. R., and Bryden, J. E. Performance of Highway Safety Devices. Research Report 57, Engineering Research and Development Bureau, New York State Department of Transportation, December 1977.

3. Guide for Selecting, Locating, and Designing Traffic Barriers. Washington: American Association of State Highway and Transportation Officials, 1977.

4. Development of Proposed Barrier Height Standards and Tolerances for Light-Post Traffic Barriers (Research Report 111, April 1984)